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Effect of Bamboo Reinforcement on the Flexural and Tensile Strengths of Concrete Beams

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Abstract

This study evaluated bamboo as a potential replacement for steel in concrete beams. The bamboo was splint into 19mm strips from the Bamboo culm. Each 19mm strip was counted as percentage reinforcement. The percentages of bamboo reinforcements used varied from 1% to 14%. One hundred and forty specimens for the flexural test were cast in 150mm x150mm x 600mm rectangular moulds and 150mm x 300mm cylindrical moulds were used for another one hundred and forty tensile test specimens. The surface of the bamboo splint was coated with bitumen and sandblasted. The concrete mix ratio was 1:2:4 with a water/cement ratio of 0.54. The bamboo-reinforced concrete beams were tested at intervals of 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30days for flexural and tensile strengths. It was observed that as the percentage of bamboo reinforcement increased, both flexural and tensile strengths increased. The maximum strength occurred at 9% at each interval of testing. In general, the test results indicated that the inclusion of Bamboo splints in concrete beams increased the load carrying capacity of the beams but not proportionately. It can therefore be recommended that Bamboo reinforcement can be used basically for light weight concrete structures as minimal/nominal reinforcement in a structure.

1. Introduction

Bamboo is one of the fastest growing plants on earth. The growth rate is dependent on local soil and climate conditions, as well as species. Bamboo is a plant belonging to the true grass family – Poaceae, subfamily – Bambusoideae, tribe – Bambuseae. In bamboo, the internodal regions of the stem are hollow and the vascular bundles in the cross-section are scattered throughout the stem. Bamboo is native to five continents around the world such as Asia, Africa, South America, North America and Australia [1]. There are totally seventy genera and one thousand, two hundred species of Bamboo all over the world. Over 2.5 billion people worldwide use or trade in bamboo worth USD 4.5 billion every year [2]. Beyond the ordinary use of Bamboo as poles, shed props and scaffolding materials during building works, Bamboo is finding a wide variety of utilities elsewhere in the world [3][4].

Bamboo will perform differently depending on the specie and maturity. Unlike steel rods, bamboo can raise many issues with respect to durability. Bamboo may contain high nutrients to foster fungi growth and insect attack. Bamboo has strong water absorption, low resistance to fire than steel and show weak bond with concrete [5][6].

Ghavami [7] discussed the mechanical properties of Bamboo, specifically pertaining to Bamboo in concrete. The study showed that the ultimate load of a concrete beam reinforced with Bamboo increased 400% as compared to un-reinforced concrete. It was found that, compared to steel, there was lower bonding between the Bamboo and concrete, and the Bamboo had a modulus of elasticity of 1/5 that of steel. The tensile strength of Bamboo can reach up to 370 N/mm^2. This makes Bamboo an alternative to steel in tensile applications [8] [9]. The density of fibres in cross-section of a bamboo shell varies with thickness as well as height [9]. Fibre distribution is more uniform at the base than at the top or the middle. This is because bamboo is subjected to maximum bending stress due to wind at the top portion of the culm [9][10]. Ghavami [11] found the strength distribution at the bottom of the Bamboo culm to be more uniform than at the top. The strength of Bamboo also increases with age and the maximum strengths are realized at age 3-4years, after which the strength begins to decrease [8][9]. The behaviour of structural concrete elements reinforced with Bamboo is reported in several research works [7][8][9][11][12][13][14] [15]. Laboratory tests were performed on ten simply-supported, one-way Bamboo reinforced concrete slabs subjected to concentrated line loads. Experimental failure loads averaged 180 percent of the theoretically predicted values [14]. The authors further tested ten Bamboo-reinforced simply supported concrete beams to failure under monotonic short term loading whilst six other beams were subjected to long term loading. Collapse mostly occurred through diagonal tension failure of the concrete in the shear span. Ghavami [7] discussed the mechanical properties of Bamboo used as reinforcement in structural concrete elements. The study showed that ultimate loads of the concrete beams averaged 400 percent of the unreinforced concrete beam capacity. Ghavami [11] studied the mechanical properties of six different types of bamboo and their behaviour in concrete. The study concluded that Bamboo can substitute steel satisfactorily and that there is the need to establish the characteristic strength of bamboo for design purposes. Umeonyiagu and Nwobi-Okoye [16] researched on the modeling and multi-objective optimization of bamboo reinforced concrete beams using ANN and genetic algorithms. A study reported in International Standard Organization ISO) [17] provided the first draft for International Standard that applies to Bamboo structures based on their performance and on limit state design. Adom-Asamoah and Afrifa [18] explored ways of making the use of bamboo reinforced concrete beams simple, efficient and cost effective for rural construction with Ghana as a case study. It was a comparative study of bamboo reinforced concrete beams with shear links made of different materials. The web materials considered were bamboo, rattan cane and steel. Sixteen (16) beams were tested to failure under four point bend tests. The highest and lowest failure loads were recorded for the cases of steel stirrups and no stirrups respectively. The experimental failure loads averaged 5.05 and 1.72 times the observed first crack and theoretical failure loads respectively. A beam performance index (BPI) in terms of energy absorbed per unit cost of beam, indicated the use of steel stirrups as the most economical. The most expensive means of shear reinforcement provision in bamboo reinforced beams is by rattan cane stirrups irrespective of the grade of concrete. It is therefore recommended that steel stirrups be used to enhance the performance of bamboo reinforced concrete beams [18].

Umeonyiagu [19] studied the use of different woods as compressive reinforcement in concrete. These woods were *Achi*, Melina and Mahogany. *Achi* wood produced the highest value of the compressive strength of all, both when cut parallel to the grain and perpendicular to it.

2. Methodology

2.1 Bamboo

Bamboo showing pronounced brown colour was used. The brownish coloration signified maturity. The longest diameters of culm were selected for large splint. It was known from literature that the finest length of Bamboo splint was approximately 19mm — providing the maximum area with the least amount of curvature [16][20][21]. The Bamboo was not cut in rainy season or early dry season. This is because culms are generally weaker due to increased fibre content in rainy season. The bamboo was seasoned and dried after cutting. The culms were split into splints approximately 19mm wide [16]. These culms were cut using a circular saw machine. The seasoned Bamboo received a waterproof coating to reduce swelling when in contact with concrete. Bitumen with grade S125 was used in this experimental work as coating material. A thin coat of bitumen was applied on the Bamboo splint using a paint brush [16]. Immediately after the application of the bitumen coat, fine sand was applied on the coated Bamboo to increase the bonding strength. Next, the Bamboo splints were left for 24hours to dry before being handled. Figure 1 shows the 19mm splinted bamboo

Figure 1 19mm splinted bamboo

2.2 Preparations, Curing and Testing of Concrete Beam Samples

In general, the technique used in conventional reinforced concrete was not changed when Bamboo was used as the reinforcement. The materials for concrete production were dried in the laboratory at least two weeks before the commencement of the project. Ordinary Portland cement was used; river sand (sharp sand) as the fine aggregate and locally sourced coarse aggregate or gravel (with a maximum size of 25mm) were also used.

Table 1 Weight of Constituents per Beam Specimen

Sample	Water (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Flexural	2.50	4.63	9.26	18.52
Tensile	0.98	1.82	3.64	7.28

A reinforced concrete mix design of 1:2:4 with a water-cement ratio of 0.54 was used. The weight of the different materials per rectangular beam (150 x 150 x 600) mm and per cylindrical beam (150 x 300)mm are given in Table 1.The water used in preparing the concrete samples satisfied the conditions prescribed in BS 3148 [16][22]. The required concrete specimens were made in threes in accordance with the method specified in BS 1881 [23]. These specimens were cured in accordance with BS 1881[24]. The testing of the beams was done in accordance with BS 1881[25] using the flexural testing machine [16][19]. Table 1 shows the weight of constituents per beam specimen. Figures 2 and 3 show the flexural and tensile crushing processes respectively.

3. Results and Discussion

Figures 4 and 5 show the graphs of tensile strengths and flexural strengths of Bamboo-reinforced beams against age respectively. It was observed that the flexural /tensile strengths increased as the age (curing days) increased. It was observed that the highest flexural and tensile strength of the reinforced concrete beam occurred at 30 -day curing at each percentage of reinforcement. The maximum value of 19.80 N/mm^2 for the flexural strength occurred at 9% reinforcement at the age of 30 days. It was noticed at each age of crushing that the flexural strengths increased when the percentage of the splinted Bamboo in the beam ranged from 1% to 9% and decreased when ranged from 10% - 14%. The maximum tensile strength value of 0.165 N/mm^2 also occurred at the age of 30 days but at the reinforcement of 5% Bamboo. Bamboo-reinforced beams failed by developing cracks gradually before it finally failed unlike the sudden failure witnessed in plain beams. It was observed that increasing the bamboo percentage reinforcement increases the chances of the bamboo to sustain load after failure. This property was more pronounced in the 9% reinforcement where the beams sustained greater amount of load thereby giving the maximum strength depending on the crushing days. The beams were not separated after failure and the bamboo splints imparted a post-cracking strength to the concrete beam. This could be attributed to the resilient nature of bamboo. It was even observed that the waterproof coating (Bitumen) applied on the bamboo splint improve the performance of the bamboo as reinforcement.

Figure 2: Flexural Crushing Processes

Figure 3: Tensile Crushing Processes

Figure 6 shows the flexural strength comparison for plain beams, Bamboo- reinforced beams and steel-reinforced beams. For the steel reinforced beam, single bars of Y10 were used. The figure shows that the flexural strengths of plain beams were about 63%, 73%, 62%, 58%, 68%, 89% and 94% of the flexural strengths of Bamboo-reinforced concrete beams at the ages of 3, 7, 14, 21, 24, 28 and 40 days respectively. Also, the flexural strengths of Bamboo-reinforced beams were about 86%, 63%, 76%, 83%, 82%, 67% and 68% of the flexural strengths of steel-reinforced concrete beams at the ages of 3, 7, 14, 21, 24, 28 and 40 days respectively.

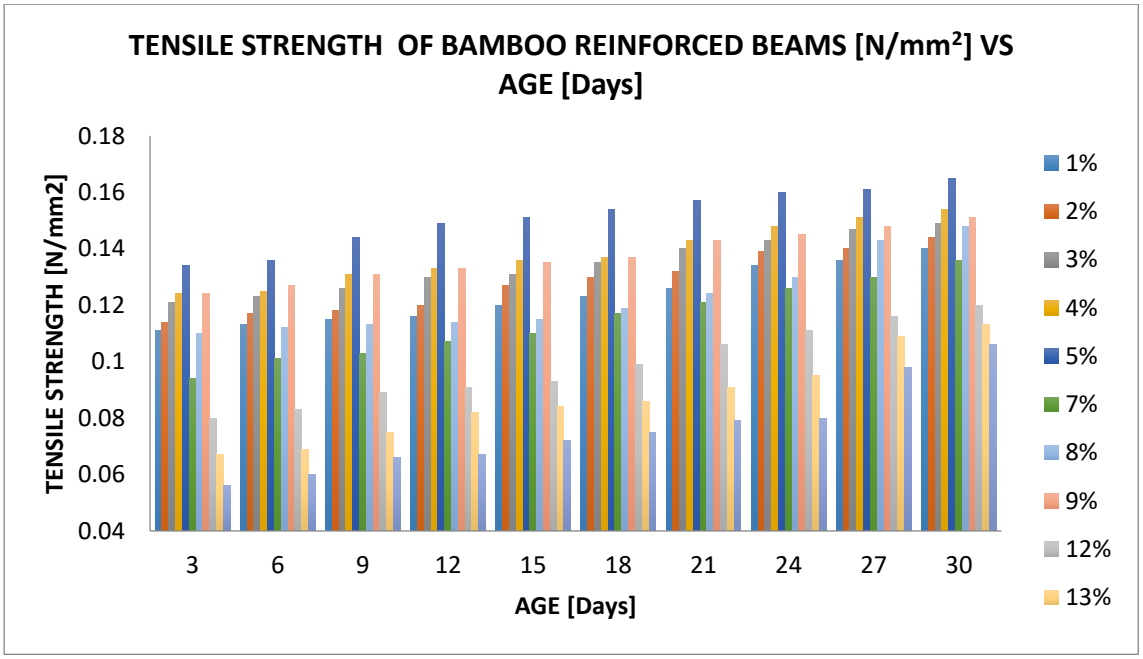

Figure 4: A graph of Tensile strength of Bamboo Reinforced Beams versus Age

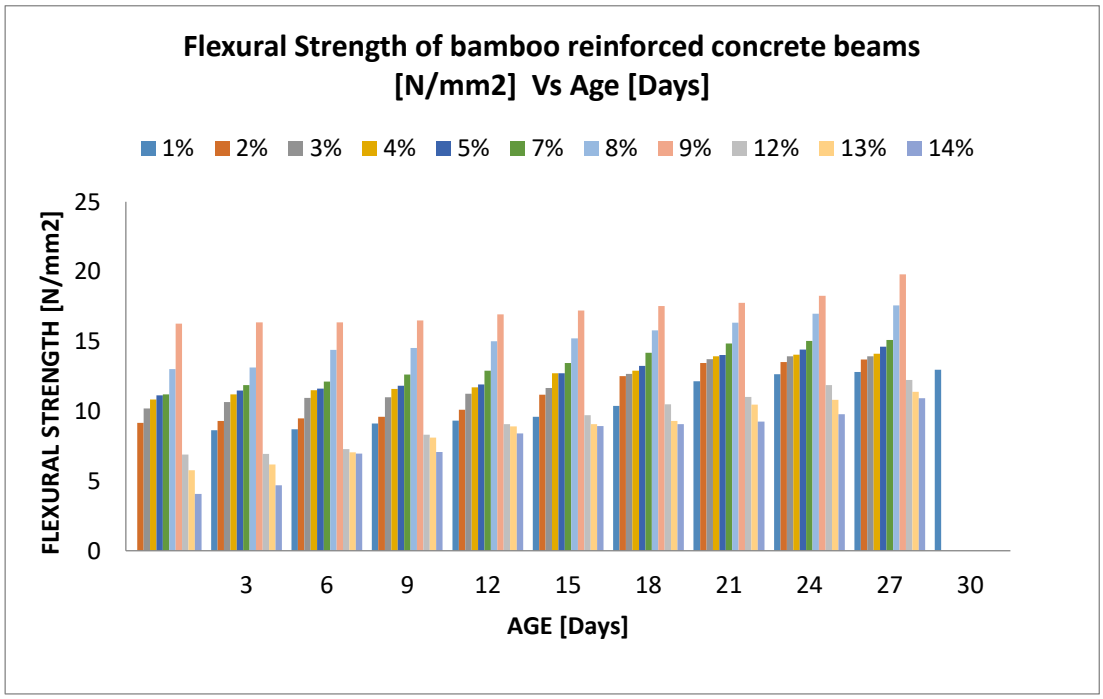

Figure 5: A graph of Flexural Strength of Bamboo Reinforced Beams vs Age

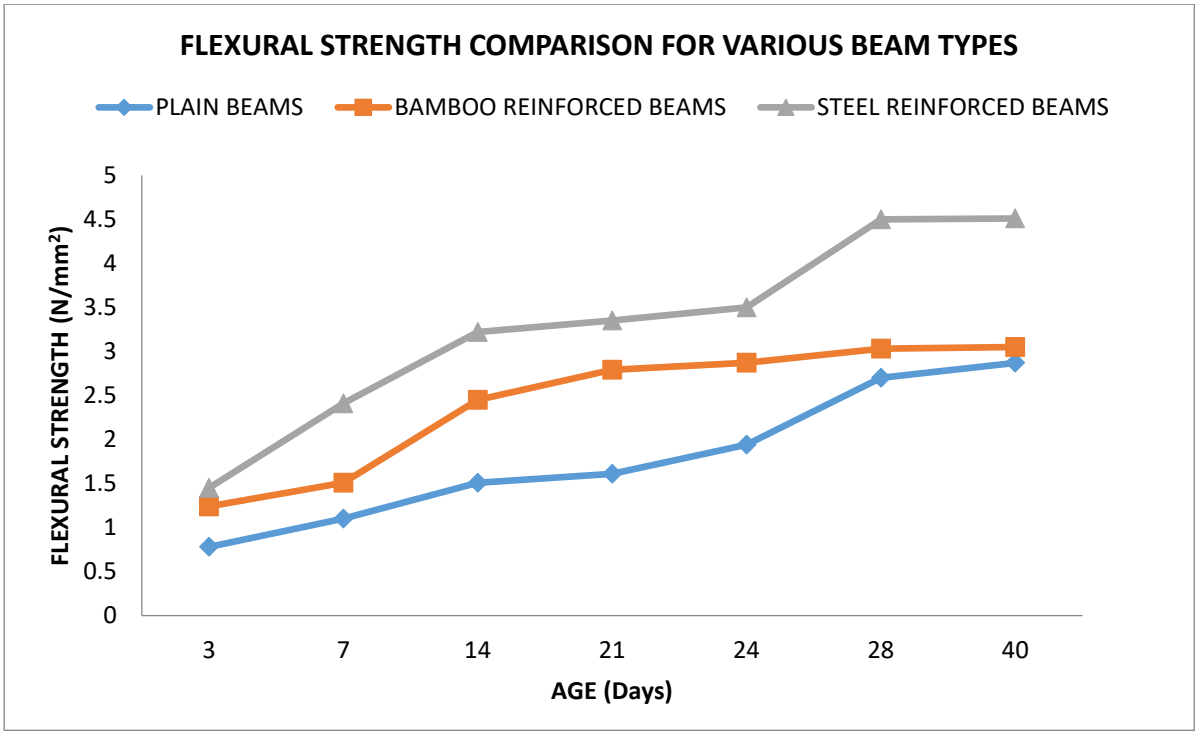

Figure 6: A graph of flexural strength comparison for plain beams, Bamboo- reinforced beams and steel-reinforced beams

Umeonyiagu [19] studied the use of different woods, cut both parallel and perpendicular to the grain, as compressive reinforcement in concrete. A total of forty-two test specimens of wood, pure concrete and concrete-wood cubes of dimensions,150 X 150 X 150cm, were made and tested for their compressive strengths. The compressive strengths produced when the wood were cut parallel to the grain were 16.84, 15.98 and 7.67 kN/mm^2 for Achi, Melina and Mahogany, respectively. Also, when cut perpendicular to the grain, the compressive strengths were 18.93, 18.69 and 20.54 kN/mm^2, for Achi, Melina and Mahogany, respectively. The research concluded that the use of these woods as part replacement for concrete does increase the compressive strength of the cubes, especially when sawn perpendicularly to the grain.

Khare [9] made the evaluation of the performance of bamboo as a potential reinforcement in concrete structural members. To achieve this objective, he made a series of tensile tests on three types of bamboo, namely: - Solid; Moso; and Tonkin — to obtain their constitutive relation. Also, four-point bending tests on concrete beams reinforced with bamboo were performed to identify their behavior compared to steel reinforced concrete members. Tensile tests specimens were prepared by cutting the bamboo typically in 13 mm wide strips of 228 mm to 305 mm in length. In order to prevent the crushing of the bamboo samples when placed in grips of the MTS machines, he epoxy-glued the end-tabs were to the bamboo samples. The results for the tensile tests which he performed indicated that the presence of nodes in Solid Bamboo samples did not affect the behavior. There was an indication too that the fracture points of the tensile samples containing nodes occurred at the nodes, which was also verified in the beam tests. Six four-point bending tests were conducted on 203 mm x 508 mm x 2429 mm reinforced bamboo concrete beams. The test results were compared with plain concrete and steel reinforced concrete beams behavior. In general, the test results indicated that bamboo reinforcement enhanced the load carrying capacity by approximately 250 % as compared to the initial crack load in the concrete beam. The study also showed that the ultimate load carrying capacity of bamboo reinforced concrete tested, on averaging all percent reinforcement, was about 35% of the equivalent reinforced steel concrete beams. The load carrying capacity of the

Moso Bamboo reinforced beam was higher than that of Solid Bamboo reinforced beam. Also, the Solid bamboo reinforced beam in general deflected less than the Moso bamboo reinforced beam indicating that Moso bamboo behaved in a more ductile manner.

In the present study, the bamboo was splint into 19mm strips from the bamboo culm. Each 19mm strip was counted as percentage reinforcement. The percentages of bamboo reinforcements used varied from 1% to 14%. One hundred and forty specimens for the flexural test were cast in 150mm x150mm x 600mm rectangular moulds and 150mm x 300mm cylindrical moulds were used for another one hundred and forty tensile test specimens. The surface of the bamboo splint was coated with bitumen and sandblasted. The concrete mix ratio was 1:2:4 with a water/cement ratio of 0.54. The bamboo-reinforced concrete beams were tested at intervals of 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30days for flexural and tensile strengths. It was observed that as the percentage of bamboo reinforcement increased, both flexural and tensile strengths increased. The maximum strength occurred at 9% at each interval of testing.

4. Conclusion and Recommendations

This study evaluated the use of bamboo as a potential replacement for steel in concrete beams. To achieve this objective, 140 samples of Bamboo reinforced-concrete beams were made using 150 x 150 x 600mm mould for flexural test and 150 x 300mm cylindrical mould for tensile test. In general, the test results indicated that the inclusion of bamboo splints in concrete beams increased the load carrying capacity of the beams but not proportionately. The strength was observed to improve as the age increased. Compared to plain concrete, bamboo reinforcement will increase the strength of concrete and it can also substitute the steel reinforcement when applied on lightweight structures.

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